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Original Article

Reliability, minimal detectable change and measurement errors in knee extension muscle strength measurement using a hand-held dynamometer in young children

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Abstract. [Purpose] Few studies have assessed the reliability of muscle strength measurement using a hand-held dynamometer, specifically in Japanese young children. This study aims to investigate the reliability, minimal detectable change and measurement error in knee extension muscle strength measurements in young children using a hand-held dynamometer. [Participants and Methods] The study participants comprised 36 kindergarten-enrolled children of 3–6 years age. An experienced physiotherapist measured their isometric knee extension strength. Appropriate orientation and practices were performed prior to measurement. The same physiotherapist took the muscle measurements twice; and the maximum value was used as the muscle strength value. The measurements were repeated at intervals of approximately 30 min to verify reproducibility. [Results] The initial isometric knee extension strength was 10.6 ± 3.3 kgf and the Intra-class correlation coefficient (1,1) was 0.765. The standard error of measurement was 1.6 kgf and the minimal detectable change was 4.4 kgf. No significant systematic errors were observed. [Conclusion] Isometric knee extension strength measurement using a hand-held dynamometer in young children has good reliability with a low risk of systematic errors.

Key words: Muscle strength measurement, Reliability, Young children

INTRODUCTION

Although manual muscle testing is conventionally used to measure muscle strength, it lacks the sensitivity to detect changes in muscle strength and is insufficient for quantification. Against this background, hand-held dynamometers (HHDs) have recently become widespread in clinical practice as a highly reliable, operable, and economical tool for assessing healthy adults[1–3], older adults[4, 5], and patients with cerebrovascular or skeletomuscular disorders[6, 7].

Many studies have reported muscle strength measurements in children using an HHD. These studies have further discussed muscle strength reference values stratified according to age and gender in healthy children and in children with disabilities[8–12]. However, no Japanese studies have yet reported on the reliability of muscle strength measurement using an HHD in healthy children. Similarly, reference values and reliability coefficients for muscle strength specific to Japanese children have not yet been investigated. Thus, the reliability of muscle strength measurement in Japanese children needs to be established to further develop its clinical applications.

The intraclass correlation coefficient (ICC), a measure of relative reliability, is often used to verify measurement reliability. The ICC can be used to express reliability strength as a coefficient ranging from 0 to 1 and enables a comparison of the reliability between different types of tests[13]. However, the ICC is not a good indicator of the actual degree of error in the

measurements taken. Obtaining absolute reliability, measured using the standard error of measurement (SEM), is considered an appropriate means to overcome the limitations of the ICC, as it provides knowledge regarding actual measurement error. The SEM indicates the range in which the true value of a measurement is included, and the degree of reliability is expressed by the unit of the actual measured value. A smaller SEM indicates a narrower error range, in which the true value is estimated to exist. The minimal detectable change (MDC) is the range of the measurement error calculated based on the SEM. The amount of change exceeding the MDC can be interpreted as a true change. We considered that the range of true values for knee extension muscle strength measurements in children and the amount of change that accurately indicates an increase or decrease in muscle strength can provide important information for determining the effectiveness of muscle strengthening and capturing muscle strength development.

Compared with a range of motion test and reflex testing, muscle strength measurement procedures are more complicated and require an examinee to have some level of understanding of the actions required, such as posture, movement, and how to apply force. When measuring muscle strength in children, there is a possibility that a measured value may have systematic or random errors, depending on the degree of understanding. Systematic errors occur when collecting data using inappropriate methods. Muscle testing in children may not reproducibly demonstrate muscle strength when the child exerts excessive force or because there is a lack of understanding of the procedure. Therefore, it is important to verify the presence or absence of systematic errors in muscle strength measurement in children, and systematic errors should be avoided using appropriate explanations and practice prior to measurement.

If the problem of systematic errors is resolved, only random errors need be considered. Random errors are incidental problems due to inattention of the examiner or examinee, instrument inaccuracy, or unpredictable environmental variations[13]. In this study, measurements were performed many times, and the average value was calculated to minimize random errors and obtain a value that closely approximated the true value. The SEM and MDC methods mentioned above can be used as statistical methods to determine the degree of random error[14].

It is essential to examine reliability, not only through verifying relative values, but also through examining how actual errors occur. As with adults, it is common for children to experience motor impairments that make it difficult to walk, run, or stand up because of muscle weakness due to injury or disease. Verifying the reliability of muscle strength measurement in Japanese children will help to accumulate basic data concerning muscle strength, and thereby promote its use as an indicator for the evaluation and treatment of the musculoskeletal system in children with motor disorders.

Therefore, this study aimed to examine the reliability of muscle strength measurements taken by the same examiner to assess knee joint extension muscle strength, which has been reported to be related to the ability to stand up and walk in young children.

PARTICIPANTS AND METHODS

The study participants comprised 36 healthy young children, aged 3–6 years, with no physical or cognitive impairment who were attending kindergarten (Table 1). Children who did not appropriately understand the measurement procedure or could not exercise as instructed were excluded. The study's purpose was explained to the kindergarten faculty and to the participants' parents, and their written consent was obtained. Kindergarten teachers accompanied the children during the

Table 1. Participant characteristics

Gender (n)	Males	18
	Females	18
Age (n)	3 years	5
	4 years	14
	5 years	14
	6 years	3
Age (years)		4.4 ± 0.8
Age (months)		58.7 ± 8.9
Height (cm)		105.4 ± 7.3
Weight (kg)		17.3 ± 3.2
BMI (kg/m^2)		15.5 ± 1.4
Lower leg length (cm)		20.5 ± 1.9
Degree of obesity (%)		0.3 ± 9.1
Dominant foot (n)	Right	32
	Left	4

Mean ± standard deviation.
BMI: body mass index.

measurement sessions to ensure their safety. This study was approved by the Ethics Committee of the Kochi Rehabilitation Institute (Receipt No. 1).

An HHD (μTas F-1, Anima Corp., Tokyo, Japan) was used to measure isometric knee extension strength. The HDD comes with a fixation belt, with better measurement reliability reported when an assessed limb is fixed to the belt and the sensor is held by the hand only[15].

Two individuals were involved in the measurement process, namely, a physical therapist with 14 years of experience whose role was to orient and conduct the measurements, and an assistant (a third-year student in the Department of Physical Therapy) whose role was to read and record the measurements.

The measurement procedure began with each child sitting at the edge of the bed. To avoid slipping, the children sat on the bed, which had a towel spread across it. In this posture, both upper limbs were folded in front of the chest, and the seat height was adjusted so that the soles of the feet were fully grounded. Next, the foot used to kick a ball was selected as the dominant side, and the sensor attachment was placed directly above the medial and lateral malleoli of the dominant side. The shape of the sensor attachment was a thick U-shape, which allowed the position of the lower leg to stabilize to the utmost extent. The fixation belt was lengthened to 90° of knee flexion and connected to the bedpost behind the lower leg. A folded towel was placed under the popliteal region to avoid any potential pain due to pressure during knee extension. Each participant was instructed to extend their knees as strongly as possible for 3 s during the measurement. A manual was prepared to avoid bias in the instructions related to the measurement; this manual provided advice on how to talk to and encourage the children to ensure that the instructions for the measurement were easy to understand, and measurements were conducted accordingly. The examiner showed each participant a model of how it moved during the measurement and encouraged them to imitate the movement. After model demonstration, the examiner passively extended the knee joint to confirm the direction of the knee joint movement. It was then actively exercised, and the measurement procedure was simulated without an HHD. After confirming that they were familiar with the measurement procedure, measurement was practiced using an HHD. During the measurement practice, tapping the front of the thigh or providing manual resistance to the distal part of the lower leg made it easier to be aware of the knee extension in order to exert muscle strength (during actual measurement, there was no manual resistance). The time for exerting muscle strength was set to 5 s, and during the measurement, the participants were verbally encouraged by counting from 1 to 5, and the timing for exerting muscle strength was clearly indicated. The examiner applauded when the participants were able to carry out the measurement procedure as instructed, and when the procedure was not conducted, the examiner carefully re-iterated the procedure that could not be carried out, and measurement was performed again after a practice session. Measurements were performed twice, and the larger value was adopted as the isometric knee extensor muscle strength (kgf). The process up to this point was considered as one session. Two sessions were conducted for each participant, with an interval of approximately 30 min between each session. The assistant recorded the measurements and concealed the readings from the examiner.

Relative and absolute reliability were analyzed. The ICC (1,1) was used to evaluate isometric knee extension muscle strength for relative reliability between the two sessions. The number of knee extension muscle strength measurements required from the calculated ICC was determined using the Spearman–Brown formula. The SEM was used to assess absolute reliability. The MDC was determined using the calculated SEM. The MDC examined the marginal range of measurement error using a 95% confidence interval (CI).

Bland–Altman analysis was used to examine systematic errors to determine the presence of fixed and proportional biases. To examine systematic error, we first created a Bland–Altman plot, a scatter plot in which the difference in measurements between the two sessions was plotted on the y-axis, and the mean of the two measurements was plotted on the x-axis. Fixed bias analysis was used to examine whether the distribution of the scatter plots was biased in a positive or negative direction using 95% CIs to determine differences between the two measurements. If the 95% CI did not contain 0, a fixed bias was considered present. In the analysis of proportional bias, Pearson's correlation coefficient was used to assess any positive or negative correlations between the x- and y-axis values in the scatter plot distribution, with a significant correlation was considered to indicate a proportional bias. The software used for the analysis was modified R commander 4.1.2 for Windows (https://personal.hs.hirosaki-u.ac.jp/pteiki/research/stat/R/), with a risk rate of 5% as the significance level.

RESULTS

Isometric knee extension muscle strength values for each section are listed in Table 2.

The ICC (1,1), SEM, and MDC values as relative and absolute reliabilities for knee extension strength measurements are shown in Tables 3, 4. The ICC (1,1) (95% CI) was 0.765 (0.589–0.873). The number of measurements to satisfy an ICC (1,1)

Table 2. Knee extension strength values (kgf) in the 1st and 2nd sessions

	1st Session	2nd Session
Knee extensor strength value (kgf)	10.6 ± 3.3	11.2 ± 3.3

Mean ± standard deviation.

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Table 3. Relative and absolute reliability of knee extension strength measurements

ICC (1,1) (95% CI)	0.765 (0.589 to 0.873)
SEM (95% CI) (kgf)	1.6 (1.3 to 2.1)
MDC (kgf)	4.4

ICC: intraclass correlation coefficient; CI: confidence interval; SEM: standard error of measurement; MDC: minimal detectable change.

Table 4. Fixed and proportional biases from Bland-Alman analysis

Fixed bias	Mean bias (95% CI)	−0.6 (−1.4 to 0.2)
Proportional bias	Slope of the regression line	0.011

CI: confidence interval.

of ≥0.9 was three. The SEM (95% CI) was 1.6 kgf (0.589–0.873 kgf), and the MDC calculated based on the SEM was 4.4 kgf. In addition, examination of systematic error revealed no significant fixed or proportional error (p>0.05).

DISCUSSION

The reliability of knee extension muscle strength measurement in children aged 3–6 years was examined, resulting in an ICC (1,1) of 0.765, indicating good relative reliability. There were no significant systematic errors in the measurements, and the analysis of random errors showed an SEM (95% CI) of 1.6 (1.3–2.1) kgf and an MDC of 4.4 kgf.

When measuring muscle strength in children, one challenge is in determining whether they fully understand verbal instructions regarding body movement. Motivation, cooperation, an ability to follow instructions, and accuracy in carrying out the movement measured can affect the reliability of measurement, especially in children. Therefore, it is recommended that clear and simple verbal explanations or practice be provided prior to measuring to obtain high reliability[11]. According to Piaget's theory of cognitive development, young children between the ages of three and six years (the age group in which the present study was conducted) exhibit intuitive and image-centered thinking. Our study manual presented the instructions in specific, plain language and through modeling. In addition, the examiner in this study had previous experience using HHD measurements in healthy children, and the utmost care was taken to prevent bias from being introduced into the process.

Although several quantitative muscle strength measurements in children employing HHDs have been reported in other countries, only a limited number of studies have used similar HDD types and units of muscle strength as those used in this study. Several studies have reported isometric knee extension muscle strength values (kgf) in different age groups, similar to our study. Daloia et al.[12] reported muscle strength values of 11.06 kgf and 13.71 kgf in 5 year-old males and females, respectively. Macfarlane et al.[11] reported an average value of 27.8 ± 5.8 lbs (equivalent to 12.6 ± 2.6 kgf) in 6 year-olds. Gajdosik[16] reported values ranging from 5.41 ± 0.84 to 5.67 ± 0.81 kg in 4 year-olds. Some reports have converted muscle strength values into torque. Hebert et al.[17] reported knee extension muscle strength values of 16.4 ± 5.8 Nm and 23.2 ± 8.1 Nm for 4- and 5 year-old males, respectively, and Eek et al.[18] reported values of 21.0 ± 5.8 Nm and 26.0 ± 4.0 Nm for 5- and 6 year-old males, respectively. If the muscle force values reported in this study had been converted to N and the muscle torque values (Nm) had been further evaluated through estimating the moment arm from the axis of the knee joint to the sensor pad of an HHD as 0.17 m, we estimate that the muscle torque values would have ranged from 18.0 to 19.0 Nm. Muscle strength data for children, including young children, have not been sufficiently accumulated in Japan, and standard values remain unclear. However, considering that data reported in previous studies and those obtained in this study differed somewhat due to differences in measuring instruments, procedures, and the ethnicity of the participants, our results were relatively similar to those reported internationally and indicate reasonable muscle strength values.

This study examined the reliability of muscle strength measurements from two perspectives: relative and absolute. Values of an ICC, which measured relative reliability, interpreted the reliability as slight (0.0–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), and almost perfect (0.81–1.00)[19]. Several studies have examined the intra-rater reliability of knee extension muscle strength measurements using an HHD in schoolchildren and have reported good intra-rater reliability with this method. Hebert et al.[20] conducted a study involving children aged 13–17.5 years, and reported an ICC (1,1) of 0.90 (95% CI 0.65–0.97). Gajdosik[16] reported ICCs (1,1) of 0.82, 0.90, and 0.54 for children aged 2, 3, and 4 years, respectively. Macfarlane et al.[11] reported an ICC (3,3) of 0.91 for children aged 6–8 years. The ICC calculated in this study was 0.77, showing good, but not excellent, reliability. However, it was estimated from the Spearman–Brown formula that a reliable muscle strength value (an ICC of ≥0.9) could be obtained if an average of at least three measurements was used. The muscle strength values in this study were the maximum of two measurements; however, using the average of multiple measurements might have improved reliability. In future, a greater number of measurements are needed to ensure reliability.

In this study, the SEM was used to measure absolute reliability. Few studies have reported SEM values when measuring

knee extension muscle strength in children. Hebert et al.[20] reported an SEM of 3.8–4.5 Nm (1.9–2.3 kgf when converted to a lower leg length of 0.2 m). The corresponding value in this study was 1.6 kgf (95% CI 1.3–2.1 kgf). Although these values were lower than those of previous studies, we considered they were reasonable based on the age and muscle strength of the study participants. The MDC calculated in this study was 4.4 kgf, and changes greater than this value can be interpreted as a true change in muscle strength in children aged 3–6 years.

Systematic errors indicate a systematic bias in the data due to a specific cause that needs to be corrected. The systematic errors in this study, namely, fixed and proportional, were examined using Bland–Altman analysis, but neither was found to be significant. We consider this was due to the examiner taking the utmost care to avoid measurement bias and ensuring a constant level of performance through planning how to talk to the children concerning the measurement procedures, and practicing the measurement procedure in advance. Another factor in preventing systematic errors is the use of an HHD with a fixation belt. The presence or absence of a fixation belt has been reported to affect the reliability of muscle strength measurement, and it is significantly more reliable to use a fixation belt for muscle strength measurement in a region with strong muscle strength[15]. Furthermore, it has been reported that reproducibility is better when a fixation belt is used, even if the muscle strength is weak[21]. In this study, the use of an HHD with a fixation belt is considered to have helped avoid systematic errors in relation to any discrepancy between the fixation of the examiner and the time when the young children exerted muscle strength. From these results, we considered it likely that any error in this measurement was random. In other words, the SEM and the MDC estimated in this study represent the spread of numerical values and the limits of errors due to random errors.

This study showed good reliability using isometric knee extension muscle strength measurements in young children aged 3–6 years, which could be performed without bias or error. However, this study had some limitations. First, the number of measurements was limited. Yamasaki et al.[22] reported that a maximum value of three measurements was desirable for knee extension muscle strength measurement in adults to obtain high reliability. However, we need to verify how many measurements are appropriate for young children, while it is statistically suggested that an average value with measurements carried out thrice has strong reliability. Second, there was an insufficient number of participants in each age group to fully verify reliability. Young children may have a different understanding of a measurement depending on their age, which may affect the reliability of that measurement. Age-specific validation is therefore essential for understanding the limitations of muscle strength measurements. Assuring reliability for each age group could allow the creation of reference values for muscle strength in children of various ages. Third, there was an issue about stabilization of the trunk during the measurement. In this study, a child sometimes let the trunk extend unintentionally, which is not enough to stabilize the trunk. If this occurred, the measurement needs to be taken again. In case of measurement using an isokinetic dynamometer with thigh and trunk straps, it is believed that stabilization of the trunk allows higher reliability[23]. Further studies are warranted that include measurement using an HHD. Finally, in terms of inter-rater reliability, measurements must be highly reproducible. In this study, reproducibility was only verified using the same examiner; therefore, it is necessary to assess inter-rater reliability in future studies.

Conflict of interest

The authors declare no conflicts of interest associated with this manuscript.

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